

Testing different stellar mass estimators at $1 < z < 2$

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Summary. — Physical parameters of galaxies (as luminosity, stellar mass, age) are often derived by means of the model templates which best fit their spectrophotometric data. We have performed a quantitative test aimed at exploring the ability of this procedure in recovering the physical parameters of early-type galaxies at $1 < z < 2$. A wide range of simulated SEDs, reproducing those of early-type galaxies at $1 < z < 2$ with assigned age and mass, are used to build mock photometric catalogs with wavelength coverage and photometric uncertainties similar to those of two topical surveys (i.e. VVDS and GOODS). The best fitting analysis of the simulated photometric data allows to study the differences among the recovered parameters and the input ones. Results indicate that the stellar masses measured by means of optical bands are affected by larger uncertainties with respect to those obtained from near-IR bands, and they frequently underestimate the real values. The M/L ratio in the V band results strongly underestimated, even when derived from the recently proposed recipe based on rest-frame optical colours (e.g. (B-V)).

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1. – Mock photometric catalogs

As a first step aimed at exploring the ability of different mass estimators in recovering the stellar mass content of early-type galaxies at $1 < z < 2$, we built a set of mock photometric catalogs. We adopted the BC03 [1] code, assuming Salpeter IMF and solar metallicity, to generate the SEDs of a wide family of models reproducing the observations of early-type galaxies. The selected SF histories are described by an exponentially declining SFR with time scale $\tau = 0.6$ Gyr, and by the superimposition of $\tau = 0.1$ Gyr models at different times simulating secondary bursts involving between 5% and 20% of the total final mass. The relevant range of redshift is described distributing the model templates at $z = 1.0, 1.5, 2.0$. The chosen combinations among ages, redshift and times of the secondary burst constitute 57 template spectra, among which 11 with no secondary star forming episodes and 16 with recent (i.e. < 1 Gyr) starburst, half of which forms 5% of the total final mass while the contribution of the other half is 20%. Finally, each generated SED is proposed with three possible values of dust extinction $A_V = 0.0, 0.2, 0.5$, assuming the reddening law of Calzetti et al. [2].

2. – Analysis

Among a wide set of templates, we searched for the one best fitting each simulated galaxy by means of the photometric redshift code *hyperz* [3]. The set of SEDs adopted to find the best fit template for each galaxy is composed by models with SFR time scales $\tau = 0.1, 0.3, 0.6, 1.0$ Gyr at solar metallicity, generated by means of the BC03 [1] code assuming Salpeter IMF. In the best fitting procedure the extinction has been allowed to vary between $A_V = 0.0$ and $A_V = 0.5$ and at each z ages have been forced to be lower than the Hubble time at that z . Assuming that the redshift is known within 0.1, we run the code with z varying between ± 0.05 of its real value. Further details on the construction and analysis of the mock catalogs can be found in a forthcoming paper (Longhetti et al. 2008 [4]).

The assumed set of parameters reproduces the choices generally made to study the photometric properties of real early-type galaxies with known spectroscopic redshift (e.g. [5]), since they include all the possible combinations of ages and dust compatible with this class of galaxies, excluding strong dust reddened star forming galaxies.

Once a best fit template has been associated to each simulated galaxy, we derived the following physical parameters:

- M_K and $M_{K_{4.5}}$ = absolute K band magnitude derived from the observed K magnitude and from the observed IR flux at $4.5\mu\text{m}$ respectively, obtained applying the k-corrections calculated on the best fit template and the dust correction derived for the best fit value of A_V ;
- $M_{K_{\text{raw}}}$ = absolute K band magnitude derived from the observed K magnitude simply applying a constant k-correction depending only from the redshift, without any dust correction;
- M_{V_J} = absolute V band magnitude derived from the observed J magnitude, obtained applying the k-correction calculated on the best fit template and the dust correction derived for the best fit value of A_V ;
- $\mathcal{M}/\mathcal{L}_K$ and $\mathcal{M}/\mathcal{L}_V$ = mass to light ratio in the K and V bands respectively, as derived from the best fit template;
- $\mathcal{M}/\mathcal{L}_V(\mathbf{B-V})$ = mass to light ratio in the V band derived as $\log[(\mathcal{M}/\mathcal{L})_V] = -0.628 + 1.305 (B - V)_0$ by Bell et al. [6], where the (B-V) rest-frame colour is derived from the best fit template;
- $\mathcal{M}(\mathbf{b})$ = stellar mass content derived from the normalization factor needed to scale the model templates to match on average the observed available fluxes (b parameter in the hyperz code);
- \mathcal{M}_K , \mathcal{M}_{V_J} and $\mathcal{M}_{V_J}(\mathbf{B-V})$ = stellar mass content derived from the absolute M_K and M_{V_J} magnitudes and assuming the mass to light ratios $\mathcal{M}/\mathcal{L}_K$, $\mathcal{M}/\mathcal{L}_V$ and $\mathcal{M}/\mathcal{L}_V(\mathbf{B-V})$ respectively;
- $M_{V_J}^{A_V=0}$, $\mathcal{M}_{V_J}(\mathbf{B-V})^{A_V=0}$ and $\mathcal{M}/\mathcal{L}_V(\mathbf{B-V})^{A_V=0}$ = parameters obtained on the sub-sample of the simulated galaxies with no dust extinction imposing $A_V = 0$ in hyperz (i.e., not affected by dust uncertainties).

Then the derived physical parameters of the simulated galaxies have been compared with their real known values (and a more detailed analysis can be found in [4]).

3. – Results

As far as the **luminosities** are concerned, from Fig. 1 it can be seen that M_K generally recovers within 0.2-0.3 magnitudes the real value in the case of the GOODS

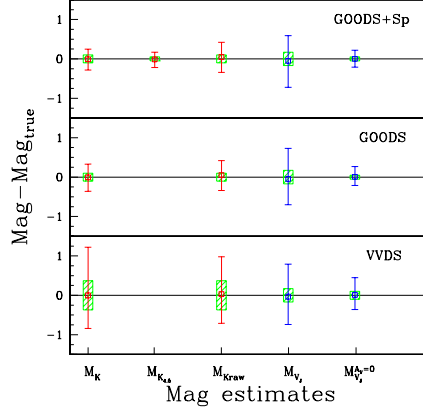


Fig. 1. – Uncertainties in the estimates of the absolute magnitudes in the K and V band. The reported errorbar represents the whole range of values spanned by the difference between the real and the recovered magnitudes. The square dot is the average value of the same difference. The shaded areas highlight the range of uncertainties of the apparent magnitudes used as the starting point to derive the absolute ones.

mock catalog [7] ($\Delta K < 0.1$ for all the simulated galaxies, $K_{lim} \simeq 21.5$) while due to larger errors in the apparent magnitudes ($\Delta K = 0.2$) the uncertainty is around 0.5 magnitudes in the case of the VVDS mock catalog [8] ($K_{lim} \simeq 20.5$), and it can raise to more than 1.0 magnitude in the case of the fainter objects (i.e. with $\mathcal{M}_{star} = 0.3 \times 10^{11} \mathcal{M}_{\odot}$ at $z = 2$ for which $K \approx 21.5$). Spitzer IR data with small errors ($\Delta(4.5\mu\text{m}) = 0.05$) allow to obtain estimates of the K magnitudes even better than 0.2 magnitudes. It is particularly remarkable that the K_{raw} values are well determined within 0.3-0.4 magnitudes when the apparent K magnitudes are affected by small errors ($\Delta K < 0.1$). This demonstrates the easiness to derive a reliable estimate of the near-IR luminosities for early-type galaxies at known redshift. In the same figure, we have reported the estimate of the V band absolute magnitude M_{V_j} that displays a much larger uncertainty than that of the K band one, partly because of large errors in the J band also for the GOODS mock catalog ($\Delta(J) = 0.15-0.20$), and partly because of the strong dust effects expected at $\lambda \simeq 5500\text{\AA}$. In Fig. 2 (left panel), the \mathcal{M}/\mathcal{L} ratios in the K and V bands are reported normalized to their true values. The retrieved values of $\mathcal{M}/\mathcal{L}_K$ are well within a factor ± 2 from the real values, and only for the fainter galaxies in the VVDS mock catalog the uncertainties grow up to 0.4-1.9. For both the two catalogs (even when analyzed with the support of IR Spitzer data) it can be noted a trend to underestimate the real value of $\mathcal{M}/\mathcal{L}_K$ by a factor of about 0.9. The underestimate of the \mathcal{M}/\mathcal{L} value in the V band is even larger (i.e. around 0.8), and the uncertainties are much larger in this band than in the K one (i.e. $(\mathcal{M}/\mathcal{L}_V)/(\mathcal{M}/\mathcal{L}_V)^{true}$ within 0.3-1.7 for the smaller errors). The values of $\mathcal{M}/\mathcal{L}_V(B-V)$ show a smaller range of uncertainties with respect to $\mathcal{M}/\mathcal{L}_V$, but the underestimate is larger. Part of this effect is due to the dust extinction, but even when only no-dust models are considered $\mathcal{M}/\mathcal{L}_V(B-V)^{A_V=0}$ is around 0.8 times the real value and the resulting uncertainty range is 0.5-1.0 for the GOODS mock catalog. Since Bell et al. [6] do not explicitly state at which mass they refer in their definition of the \mathcal{M}/\mathcal{L} ratio, it is possible that their proposed formula has to be considered for the mass still locked into stars (as often assumed when dealing with the stellar content of galaxies) that

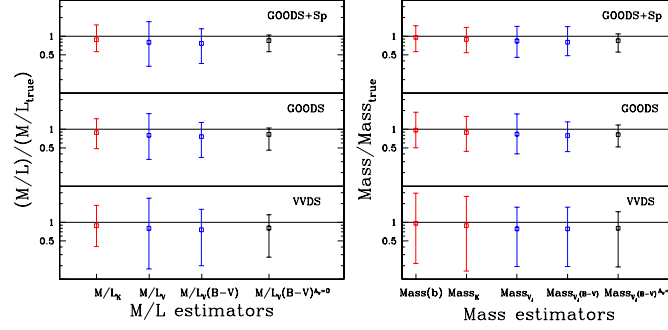


Fig. 2. – Retrieved mass to light ratios M/L in the K and V bands (left panel) and mass values (right panel) are reported as normalized to their true values (see previous section for detailed definitions)

is expected to be around 0.7-0.8 of that adopted in the present paper (resulting from the integration of the SFR over the time up to the age of the model).

On the right panel of Fig. 2, the retrieved **mass** values obtained by means of different estimators are reported normalized to the true values. The mass estimate obtained by means of the template scaling factor (e.g., b parameter of *hyperz*) is the better determined with respect of any other estimator ([4]). The values of \mathcal{M}_K are those which closer approach the previous ones, even if on average they slightly underestimate the real values. The trend towards the underestimate of the masses is much more marked when calculated with the V luminosities and both $\mathcal{M}/\mathcal{L}_{V_j}$ and $\mathcal{M}/\mathcal{L}_{V_j}(B-V)$, for which the recovered masses are only 70-80% of the real values on average, and the dispersions around the real values are much larger than the previous cases.

Summarizing, when spectro-photometric data are used to find the best fit templates reproducing the observed early-type galaxies, it is easier to obtain a good determination of near-IR absolute luminosities than optical ones, and the best mass estimate, not affected by any systematic trend, is that derived by the scaling factor between templates and data on average. Alternatively, the near-IR bands can be safely used to derive the mass content of early-type galaxies, while optical bands produces much larger uncertainties and general underestimate of the stellar masses which are difficult to be taken into account.

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